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Technical Note

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How to Switch a Beam-Forming Network with Minimum Disturbance to Existing Communication Channels

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Prepared for the Defense Communications Agency
under Electronic Systems Division Contract F19628-76-C-0002 by

Lincoln Laboratory

The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology, for the Military Satellite Office of the Defense Communications Agency under Air Force Contract F19628-76-C-0002.

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ESL TP-76

HOW TO SWITCH A BEAM-FORMING NETWORK WITH MINIMUM DISTURBANCE TO EXISTING COMMUNICATION CHANNELS

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TECHNICAL NOTE 1976-20

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ABSTRACT

A beam-forming network (BFN) consisting of a tree of variable power dividers (VPD's) is typically used to divide the power among beams in a multiple-beam antenna. During the changeover from one set of beam configurations to another it is important that a user who is present in both configurations does not have his communication channel disturbed. A procedure is presented for systematically changing the VPD's, first to an intermediate configuration, and then to a final configuration, which avoids any disturbance to continuing users.

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I. Introduction

Previous reports[1,2] have described a multiple-beam antenna for satellite-to-earth communication consisting of a microwave lens fed by an array of horns. Power is divided among the horns to vary the antenna pattern at will by means of a beam-forming network (BFN) which consists of a number of variable power dividers (VPD's) in a corporate structure array. Such an antenna has potential usefulness as a satellite-borne communication antenna in a situation where coverage patterns on the earth must be changed from time to time to fit changing communication needs.

A schematic diagram of a 16-output BFN is shown in Fig. 1. Each junction in this diagram represents a variable power divider, which typically consists of two hybrid junctions and two phase shifters in a bridge circuit.[3] The differential phase shift between these phase shifters is varied to vary the power division between the two output ports of the bridge.

This technical note addresses the problem of how to switch the BFN from one power distribution to another without causing the EIRP of a continuing user (one who maintains communication in both distributions) to be interrupted during the switchover. A procedure is presented for reconfiguring the BFN in such a way as to cause minimum disturbance (a drop of 3 dB or less) to such a user. The specific requirement is that a continuing user experience a drop in EIRP of no more than 3 dB below the present or new EIRP, whichever is smaller. The temporary 3 dB drop in power is to take place over a short time and allows for the use of latching ferrite phase shifters[3] in the VPD's. The 3 dB value is due to the fact that when the power division of a VPD is

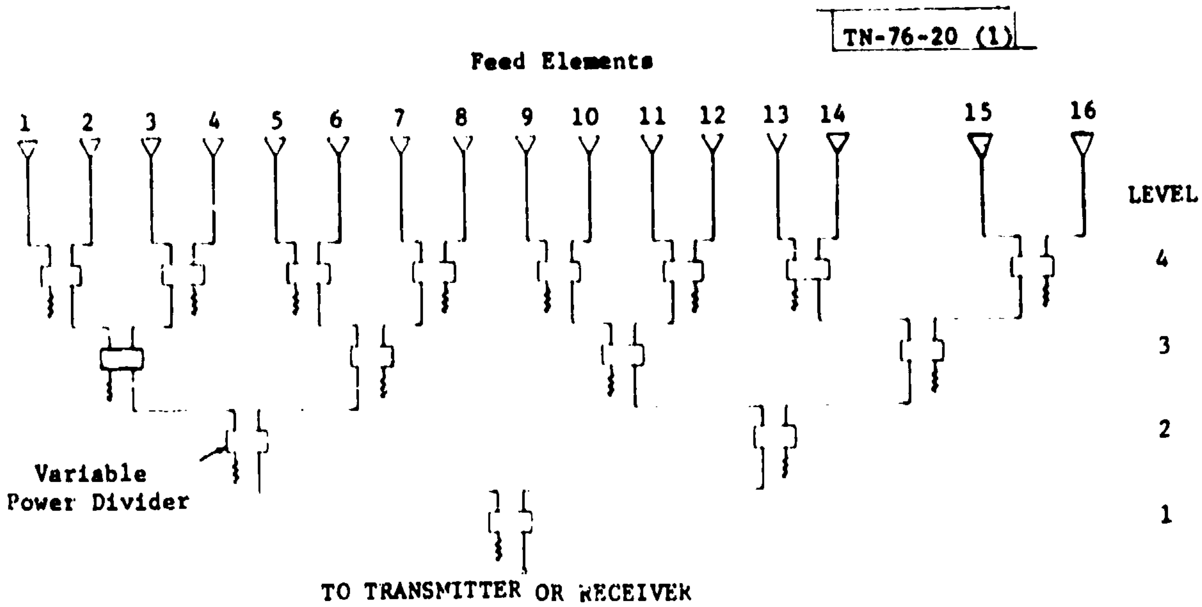


Fig. 1. 16-Element beam-forming network, schematic

changed, the ferrite phase shifters go through a reset-set sequence, with the reset state resulting in nominally equal power division between its output ports. Thus a 3 dB power drop can occur in certain cases for a short period of time. In order to limit this drop to a maximum of 3 dB, the VPD's must be switched one level of the BFN at a time rather than all levels simultaneously. (In the latter case the 3 dB drop could increase to 3N dB where N is the number of levels.)

In accordance with the above requirement, an algorithm has been devised which ensures that the power drop never exceeds 3 dB below that of the initial or final power setting of any port of the BFN, and this drop only occurs during the reset time of the ferrite phase shifter. The algorithm requires that the VPD's be set in successive levels starting from the Nth level, proceeding to the first level and then back up to the Nth level. The Nth level is adjacent to the M-port end of a 1:M BFN. The first level has a single VPD; whereas the Nth level has M/2 VPd's, where $M = 2^{N-1}$, (see Fig. 1).

II. Algorithm

Nth Level through 2nd Level

1. If the total power into a VPD increases when going from the initial distribution to the final distribution, do not set the VPD to the final power division.

2. If the total power into a VPD decreases or remains constant, when going from the initial distribution to the final distribution, set the VPD to the final power division.

First Level

1. Set the single VPD to the final power division.

Second Level through Nth Level

1. Set all VPD's that have not been previously set to their final power division.

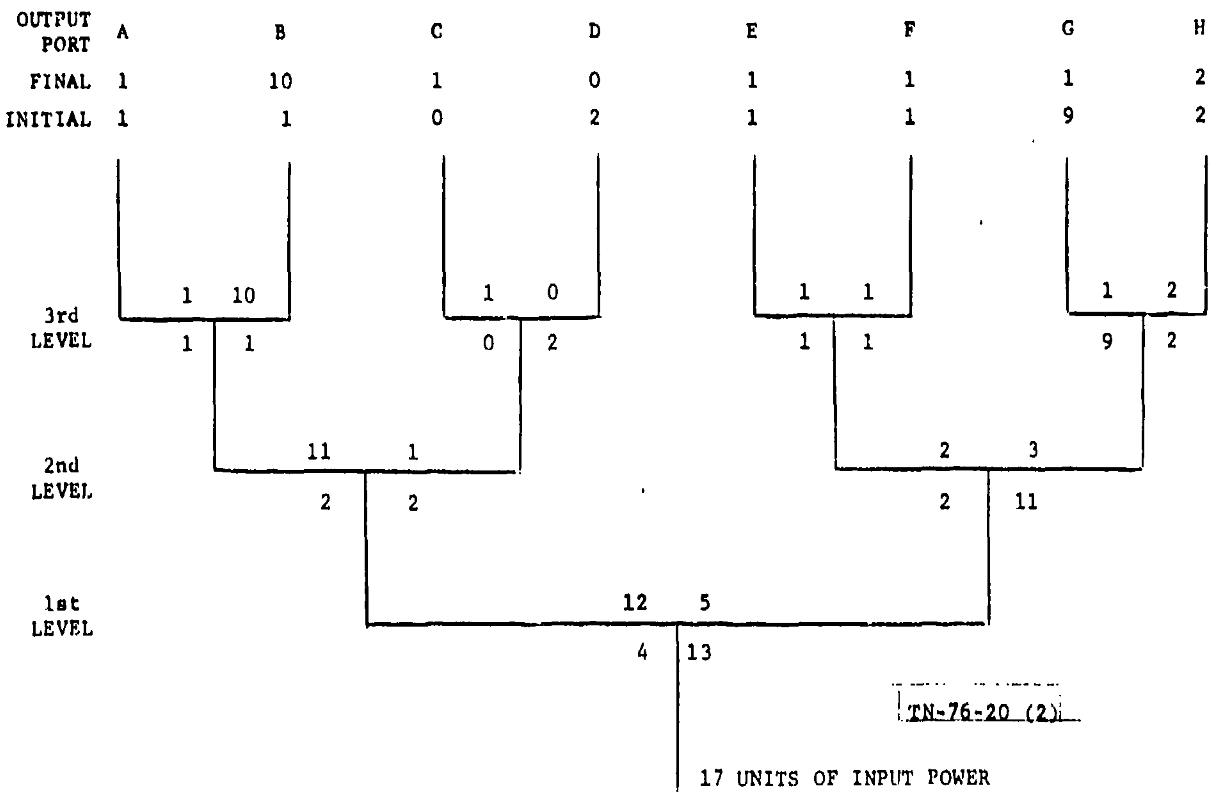
Note: At any level all of the VPD's, if of the latching ferrite variety, must go through the reset-set cycle (even if their power divisions are not to be changed) in order to maintain the same insertion phase at all ports.

The use of the above algorithm requires that the total power into all VPD's (normalized to the input power to the first level VPD) first be computed for both initial and final distributions. However this must be done anyway, in order to determine the proper settings for each of the VPD's.

Utilizing Fig. 2 which shows a BFN for an 8-beam system an example of the use of the algorithm follows,

Level of Switching	Output Power Units on Ports							
	A	B	C	D	E	F	G	H
Initial	1	1	0	2	1	1	9	2
3rd Level	1	1	2	0	1	1	11/3	22/3
2nd Level	1	1	2	0	13/5	13/5	39/15	78/15
1st Level	1	1	6	0	1	1	1	2
2nd Level	11/2	11/2	1	0	1	1	1	2
3rd Level and final	1	10	1	0	1	1	1	2

In the above example it is noted that the power level on any port does not drop below the smaller of its initial or final values. If instead of this procedure, the first VPD in the 3rd level had been switched first to its final value, the power at A would have dropped by 10 dB and similarly if the 1st



NOTE: UPPER NUMBERS ARE POWER DIVISIONS FOR FINAL DISTR.
LOWER NUMBERS ARE POWER DIVISIONS FOR INITIAL DISTR.

Fig. 2. Example of use of algorithm

level VPD had been switched first, power at ports EFG would have dropped by 4 dB.

III. Proof of Algorithm

In order to prove that this algorithm provides the desired results, consider a typical path through a BFN as shown in Fig. 3. (Figure 3 represents a portion of a 32-port BFN.) P_i represents the power into the typical VPD, at the $(i+1)^{th}$ level. C_i represents the power coupling coefficient of the ith VPD, a number between 0 and 1, (assuming lossless VPD's) and is the number relating the coupling from one VPD to the next so that

$$P_{i+1} = C_{i+1} P_i$$

It is assumed that P_o, the input power level, remains unchanged. We will prove the algorithm for the path shown for a 5-level BFN, and by extension this will prove it for any path through the BFN. A similar proof holds for a BFN of any number of levels. We also consider only a transmitting antenna, but the same argument holds true for a receiving antenna. Let $P_i^{(1)}$ and $C_i^{(1)}$ be the initial values of P_i and C_i, $P_i^{(2)}$, and $C_i^{(2)}$ be their final values. We wish to show that $P_5 \geq P_5^{(1)}$ or $P_5 \geq P_5^{(2)}$ at all times while going through the steps of the procedure.

A. Step 1

Following the rules of the algorithm, set the 5th level of VPD's:

1. If $P_4^{(1)} < P_4^{(2)}$, C_5 remains at $C_5^{(1)}$. P_5 thus remains unchanged, at its initial value.

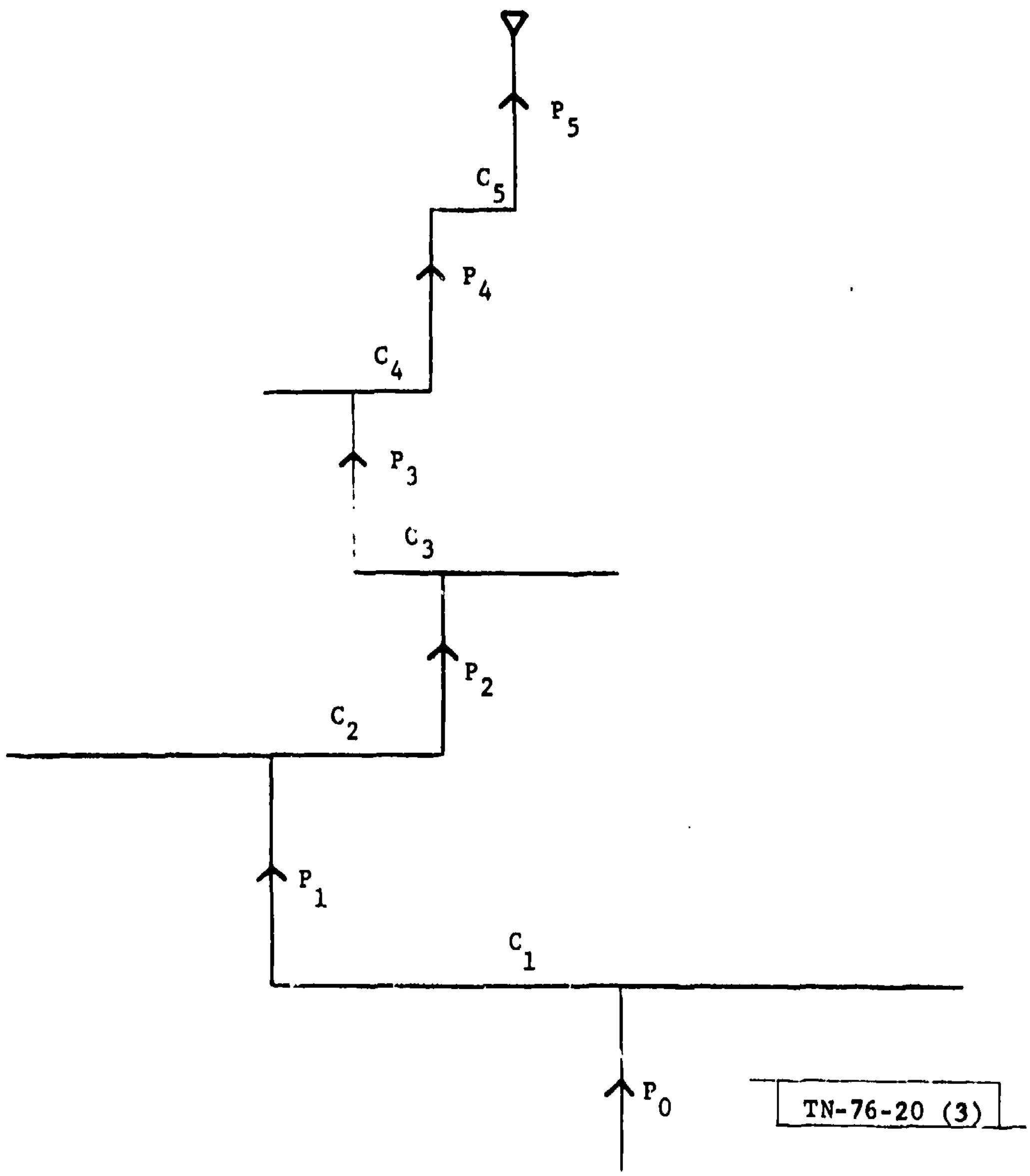


Fig. 3. Typical path through a BFN

2. If $P_4^{(1)} \geq P_4^{(2)}$, set C_5 to its new value, $C_5^{(2)}$. P_5 now becomes $P_5 = C_5^{(2)} P_4^{(1)} \geq C_5^{(2)} P_4^{(2)} = P_5^{(2)}$, so P_5 is greater than or equal to its final value.

Thus in Step 1 we have satisfied the requirement. (This step is outlined in Fig. 4.)

B. Step 2

Set the 4th level of VPD's.

1. If $P_3^{(1)} < P_3^{(2)}$, C_4 remains unchanged at $C_4^{(1)}$, and thus P_4 remains at $P_4^{(1)}$. We have changed nothing at this step so P_5 is unchanged.

2. If $P_3^{(1)} \geq P_3^{(2)}$, change C_4 to $C_4^{(2)}$. P_4 then takes on an intermediate value, $P_4^I = C_4^{(2)} P_3^{(1)} \geq C_4^{(2)} P_3^{(2)} = P_4^{(2)}$. If $C_4^{(2)} \geq C_4^{(1)}$ then $P_4^I \geq P_4^{(1)}$ and P_5 is thus increased or remains unchanged in this step. If however $C_4^{(2)} < C_4^{(1)}$, then $P_4^I < P_4^{(1)}$, and we must have reduced P_5 in this step. However, if $P_4^I < P_4^{(1)}$, then $P_4^{(2)} < P_4^{(1)}$ and thus C_5 will have been set to its new value, $C_5^{(2)}$, in Step 1. Therefore in this step P_5 becomes $P_5 = C_5^{(2)} P_4^I \geq C_5^{(2)} P_4^{(2)} = P_5^{(2)}$, and so P_5 is greater than or equal to its final value, as desired.

(This step is outlined in Fig. 5.)

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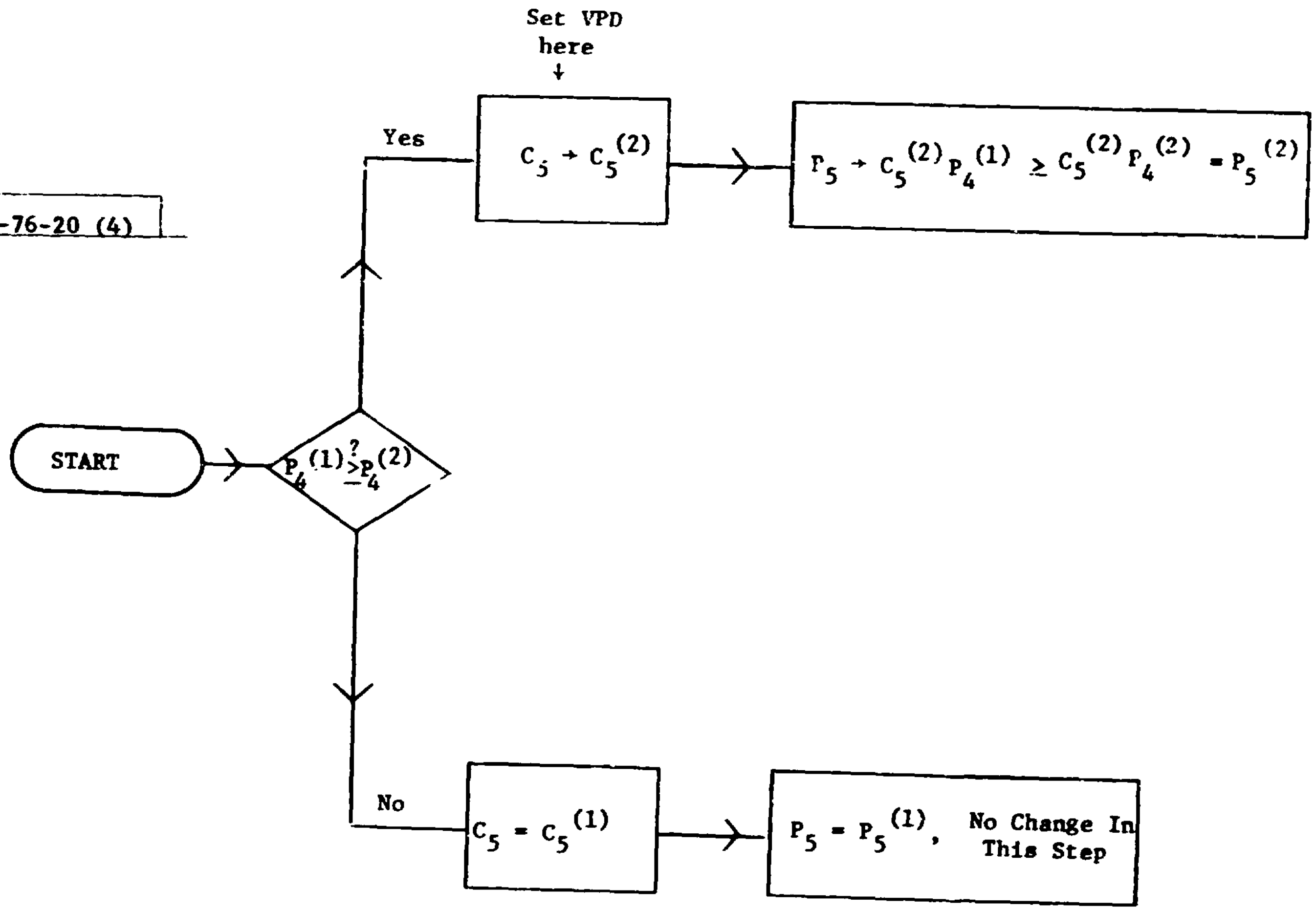
STEP 1

(Fifth Row)



$\therefore P_5 \geq P_5^{(1)}$ or $P_5^{(2)}$ At End of Step 1

Fig. 4. Outline of Step 1

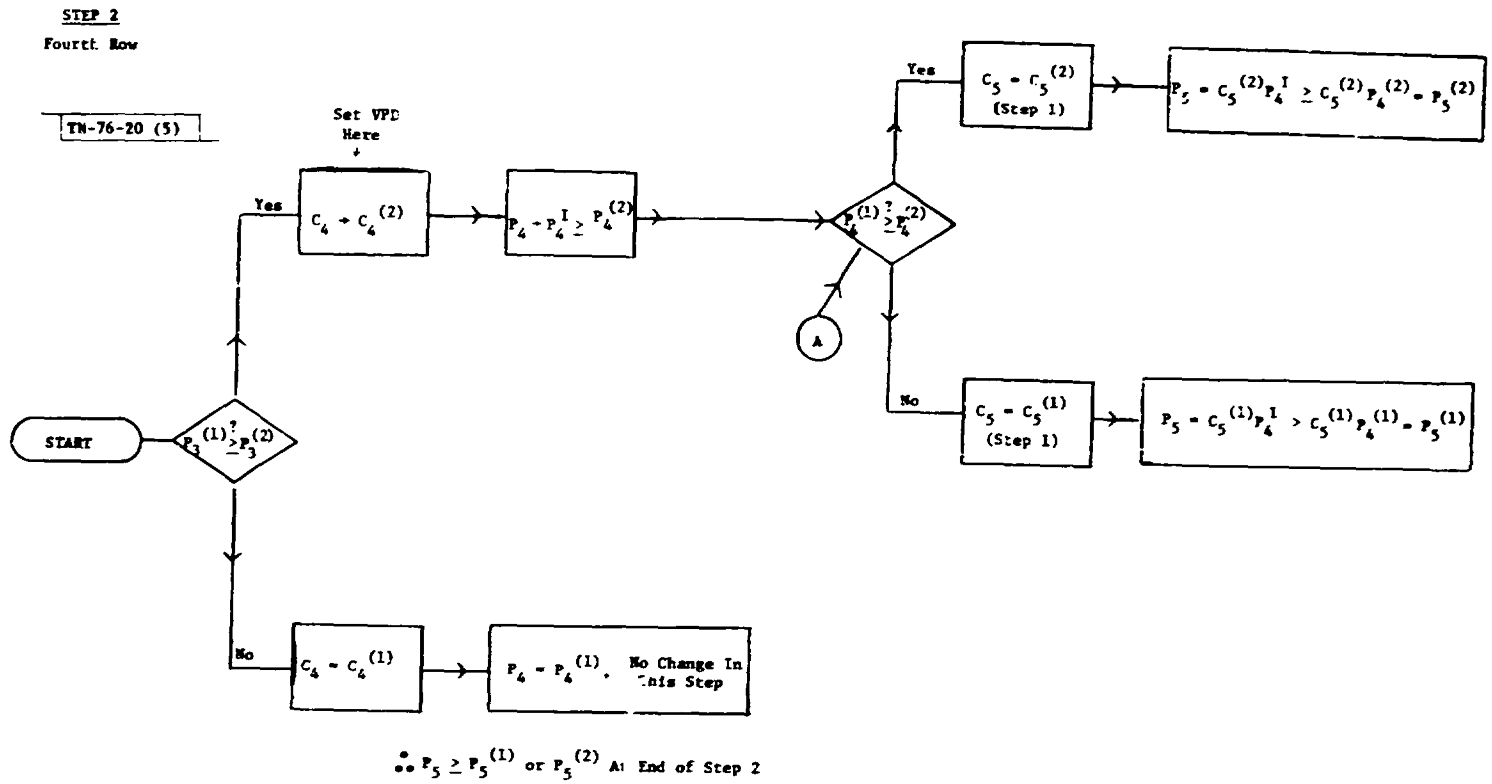


Fig. 5. Outline of Step 2

C. Steps 3-5

Similar arguments may be carried out for setting each level of VPD's to their intermediate states. The logic for Step 3, for example, is outlined in Fig. 6.

D. Step 6

In Step 6, we start back up the tree, setting level 2 to its final value. We need only be concerned if we have not yet set C_2 to its final value, in Step 4, and if $C_2^{(2)} < C_2^{(1)}$, which would reduce P_2 and would thus reduce P_5, possibly below the desired level. The upper part of the tree is, at this point in the procedure, set so that P_5 is at an acceptable level if $P_2 = P_2^{(1)}$, a situation which was the case just before Step 5. Thus we need only be concerned if, after this step, P_2 is reduced below $P_2^{(1)}$. The level of P_2 after this step is $P_2 = C_2^{(2)}P_1^{(2)} = P_2^{(2)}$, so we are concerned only if $P_2^{(2)} < P_2^{(1)}$. But if this is the case, then C_3 will have been set to its final value, $C_3^{(2)}$, in Step 3, and so setting C_2 in this step merely sets P_3 to its final value. The same argument now holds at level 4: We can only have a possible problem if P_3 is reduced in this step below its initial value. But if $P_3^{(2)} < P_3^{(1)}$, C_4 has already been set to its final value in Step 2, and so setting C_2 in this step will set $P_4 = P_4^{(2)}$. If $P_4^{(2)} < P_4^{(1)}$, C_5 will

STEP 3

Third Row

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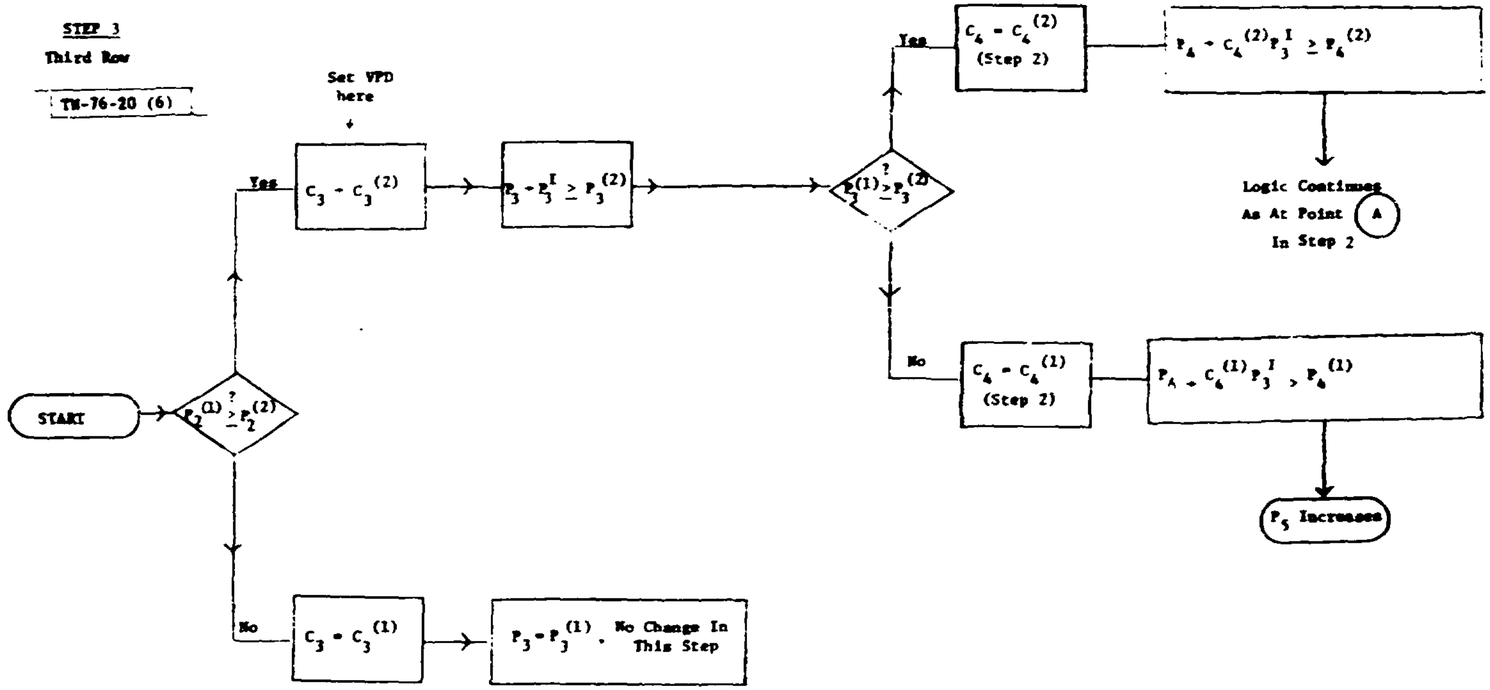

$\therefore P_5 \geq P_5^{(1)}$ or $P_5^{(2)}$ At End of This Step

Fig. 6. Outline of Step 3

have been set to $C_5^{(2)}$, and the effect of this step will be to set P_5 to its final desired value.

This argument is outlined in Fig. 7, and a similar argument holds for each of Steps 7, 8 and 9 in which Levels 3, 4 and 5 are set to their final values.

Thus we have shown that the proposed algorithm satisfies the requirement that P_5 remains greater than or equal to its initial or final value after each step in the procedure.

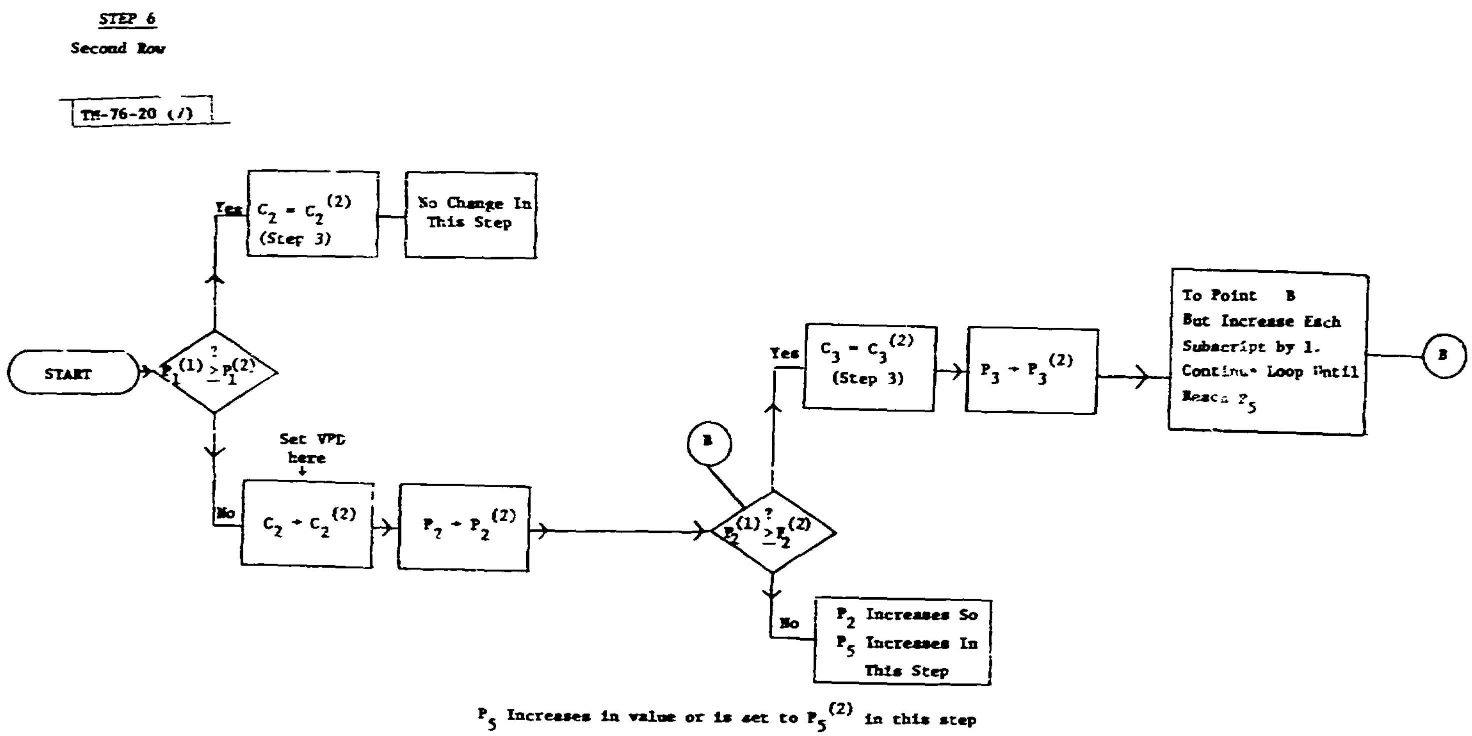

Fig. 7. Outline of Step 6

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1. REPORT NUMBER ESD-TR-76-74	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) How to Switch a Beam-Forming Network with Minimum Disturbance to Existing Communication Channels		5. TYPE OF REPORT & PERIOD COVERED Technical Note
		6. PERFORMING ORG. REPORT NUMBER Technical Note 1976-20
7. AUTHOR(s) Lorne K. DeSize and Alan J. Simmons		8. CONTRACT OR GRANT NUMBER(s) F19628-76-C-0002
9. PERFORMING ORGANIZATION NAME AND ADDRESS Lincoln Laboratory, M.I.T. P.O. Box 73 Lexington, MA 02173		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Communications Agency 8th Street & So. Courthouse Road Arlington, VA 22204		12. REPORT DATE 2 April 1976
		13. NUMBER OF PAGES 24
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Electronic Systems Division Hanscom AFB Bedford, MA 01731		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

None

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

beam-forming network	multiple-beam antenna
variable power dividers	satellite communications

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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